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THE COMPARISON OF GEOLOGICAL CONDITIONS OF AMERICAN UNCONVENTIONAL OIL FIELDS AND KROSNO BEDS

1. INTRODUCTION

Crude oil production from unconventional sources has increased greatly in recent times, being now one of the most important sources of energy in the world, especially in the United States, where there are 48 currently operating reservoirs of “shale plays” type (Fig. 1). This is due to the favorable geological conditions of occurrence of these reservoirs, as well as using highly developed technology. The success of oil production from shale on the American continent has contributed to the increase of the interest in this type of reservoirs in other countries, including Poland. Prospective areas of the occurrence of accumulations of hydrocarbons in shale rocks extend through entire Poland from NW to SE in the Ordovician-Silurian pool. Nevertheless, the interest of geologists is focused also on the Outer Carpathians. Krosno beds that occur there are characterized by alternating sandstone-shale packages of low petrophysical properties. These layers can be considered as potential unconventional hydrocarbons resource.

This work summarizes the four US geological formations treated as unconventional crude oil reservoirs. These are the Eagle Ford, Bakken, Avalon & Bone Springs and Monterey. The geological conditions of occurrence of these formations are compared with the terms of Krosno beds.

1.1. Eagle Ford

The Eagle Ford formation is located in the Texas pool, Maverick, Texas. The Eagle Ford Shale was traditionally known as a source rock in South and East Texas for the Austin Chalk formation. The first true Eagle Ford Shale well as drilled in 2008 [1].

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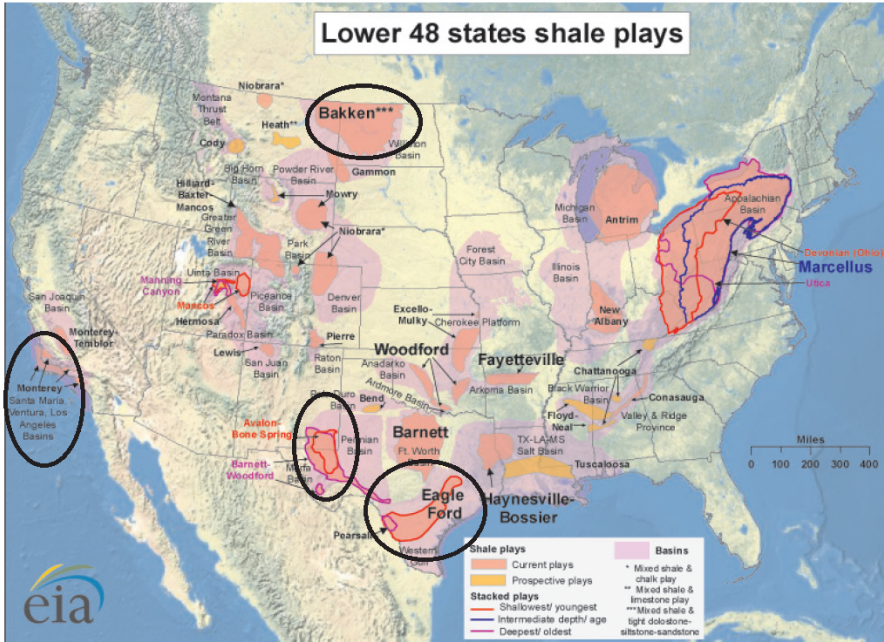


Fig. 1. Location of “shale oil play” on a background map of the United States (Source: U.S. Energy Information Administration based on data from various published studies. Update: May 9, 2011)

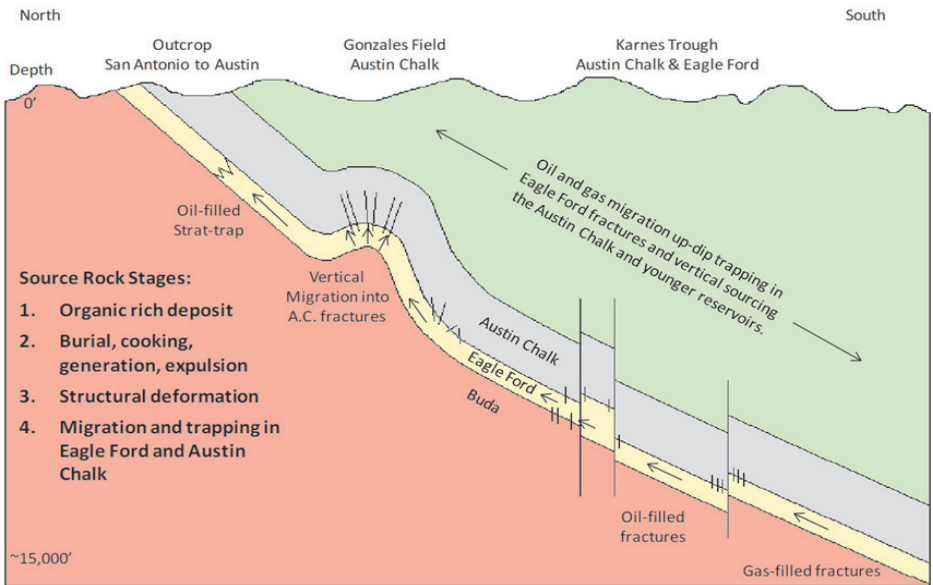


Fig. 2. Eagle Ford Shale: both source rock and resource [1]

Eagle Ford Formation contains oil-gas reservoirs. The area of occurrence of purulent zone is approx. 5800 km². Bedrock and at the same time the reservoir are Eagle Ford “slates” (containing up to 70% of carbonates, hence it is better identify them as clayey carbonate rocks) of Cretaceous age (Cenomanian-Turonian) – Figures 2 and 3. They are characterized by a porosity of approx. 9%, organic carbon content (TOC) approx. 4.25% and thickness approx. 70 meters. Burying depth varies and reaches up to 5000 m (rocks are exposed on the surface as well) [2].

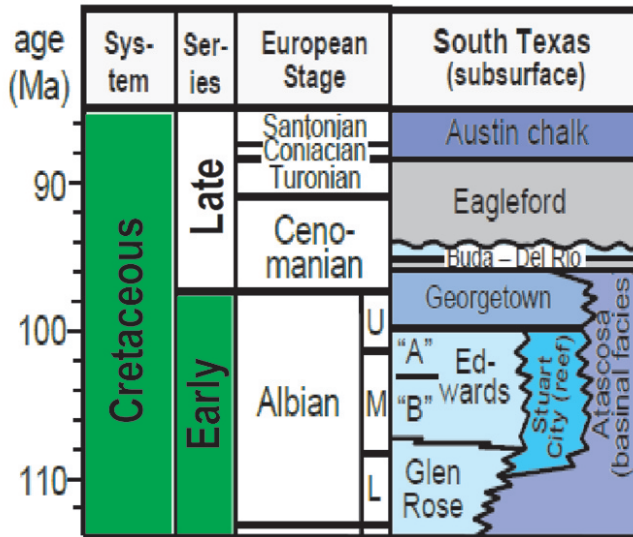


Fig. 3. Upper Cretaceous stratigraphic column showing the Eagle Ford Shale [1]

1.2. Avalon & Bone Springs

Avalon & Bone Spring formation [2, 3] is located in the Permian Basin in the SE part of the state of New Mexico and western Texas. The surface area of the reservoir is approx. 3400 km². Avalon formation are mudstones rich in the organic matter interbedded with the layers of carbonate rocks, which are located within the carbonate platforms. The content of organic carbon in Avalon mudstones reaches up to 12% (average 5% TOC). Bone Springs Formation are sandstones and carbonates, characterized by low reservoir properties, so that the operation requires the use of advanced technologies. Their age is lower permian (Kungurian). The stratigraphy of Avalon & Bone Springs formation is presented at Figure 4. Thickness of Avalon & Bone Springs layers reaches up to 500 meters, and the depth to of approx. 3000 meters.

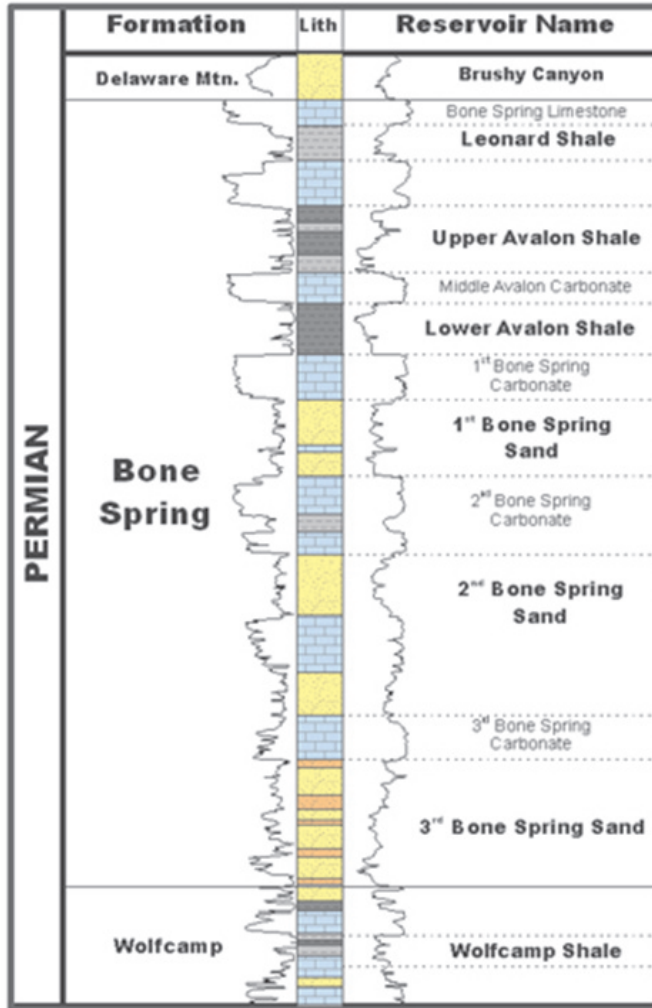


Fig. 4. Delaware Basin Stratigraphy (modified from [4])

1.3. Bakken

Bakken formation [2] is located in the Williston in Montana and North Dakota pool. It contains one of the largest reservoirs in the United States, which occupies an area of approx. 52,000 km². Reservoir formation consists of three parts. The lower part is represented by black shales rich in organic matter (approx. 11% TOC), which are very good bedrock. Their thickness is approx. 6–8 meters. The central part are mudstones with sandstone inserts, sometimes with limestone and dolomitic siltstones inserts. The average thickness of this section is approx. 13–15 meters. The upper part is lithologically

similar to the bottom part, with the TOC value of 11%, its average thickness is approx. 7–10 meters. All parts of formation are presented at Figure 5.

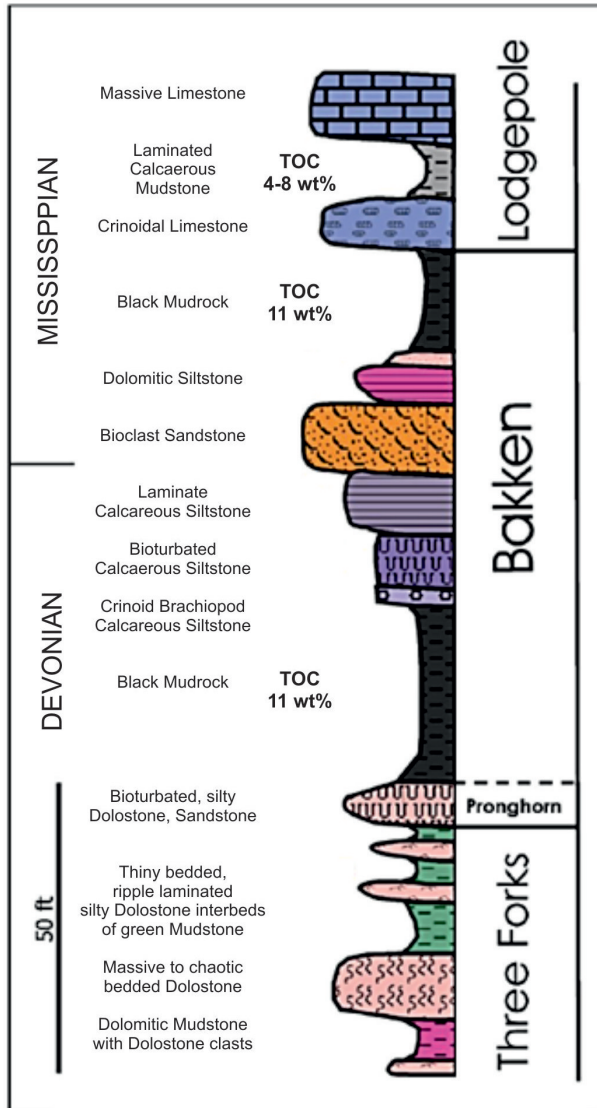


Fig. 5. Stratigraphic chart of the Bakken petroleum system (modified from [14])

The average thickness of the entire formation is approx. 25–30 meters, its age is estimated to be the Upper Devonian-Lower Mississippian. Reservoir parameters are characterized by low values (porosity approx. 5%, the permeability of average 0.03 mD).

According to the resources [5], reservoir quality is associated with the slots and microfuge which locally increase the reservoir parameters of rocks.

1.4. Monterey

Monterey Formation [2, 6] is located in the basins of the San Joaquin and Los Angeles, California. The area is approx. 4500 km² in both pools. Compared to the previously described formation this one is very young, Monterey and Santos rock formations are referred to as Neogene (6–16 million years). These shales and mudstones with organic matter, with interbeddings of sandstones can serve as a reservoir. Just like in the Carpathian Mountains, the rocks are strongly folded and slided, the depth of the formation reaches 5,000 meters, and its thickness – 700 meters. The porosity of the Monterey formation is estimated at approx. 11% and the TOC content is equal to approx. 7%. The shales of Monterey formation are the bedrock for many fields in California. The stratigraphy and cross sections of Monterey formation are presented at Figures 6 and 7.

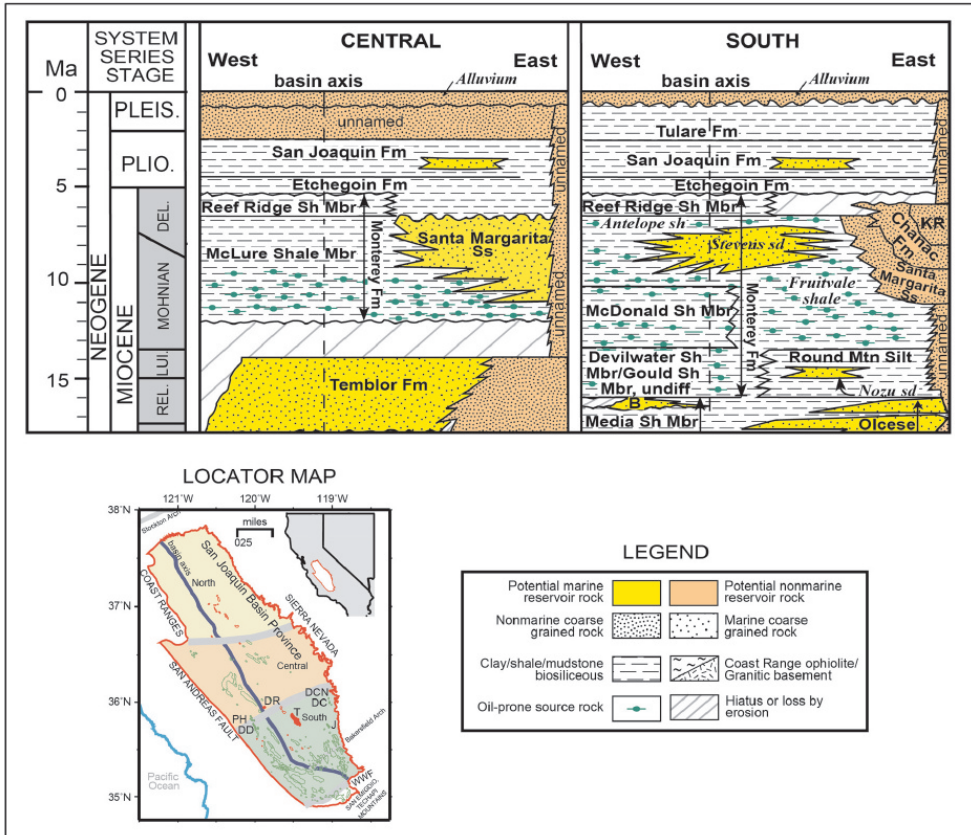


Fig. 6. Stratigraphy and lithology of the Monterey formation [6]

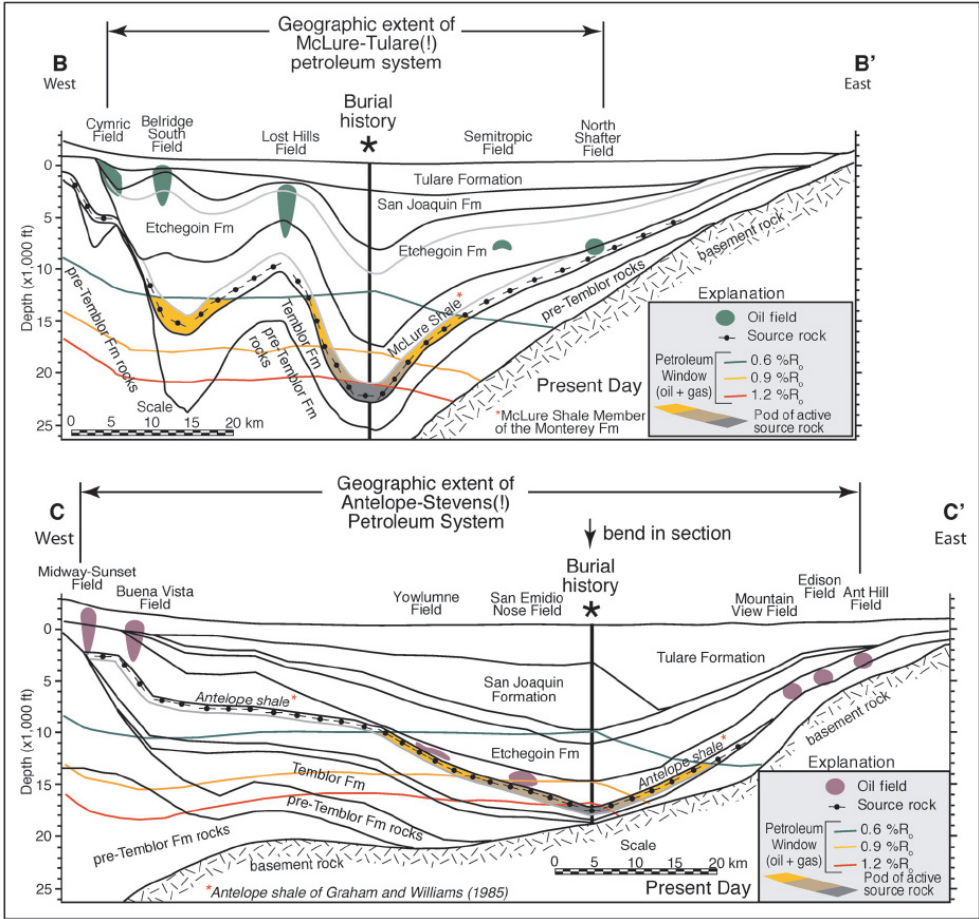


Fig. 7. Geological cross-sections through the formation of Monterey in San Joaquin basin [6]

2. GEOLOGICAL CONDITIONS OF KROSNO BEDS IN THE CONTEXT OF THE UNCONVENTIONAL OIL PRODUCTION

Krosno beds are present in Carpathians in different tectonic units in the area of Poland and abroad. Carpathians (in Poland) are divided into five main tectonic units, from south [17]: Dukla nappe, Magura nappe, Silesian nappe, Sub-Silesian nappe and Skole nappe. The largest part of Krosno beds is observed in SE Poland in Silesian nappe, it declines to the west [7, 8, 14, 15]. Its thickness goes to 3500 m [18]. They are thick-bedded sandstones from Oligocene age, gray, fine- and medium-grained, calcareous, with frequent coal-rank plant detritus. They are characterized by the presence of numerous fractures filled with calcite. Slate gray and dark gray interbeddings are present.

Krosno beds are divided into upper (with a predominance of shell sandstones), medium (with a predominance of coarse-bedded sandstones) and lower (with numerous black shale menilite interbeddings). The occurrence of Krosno beds in SE Poland and geological setting of SE Polish Outer Carpathians is presented at the Figure 8.

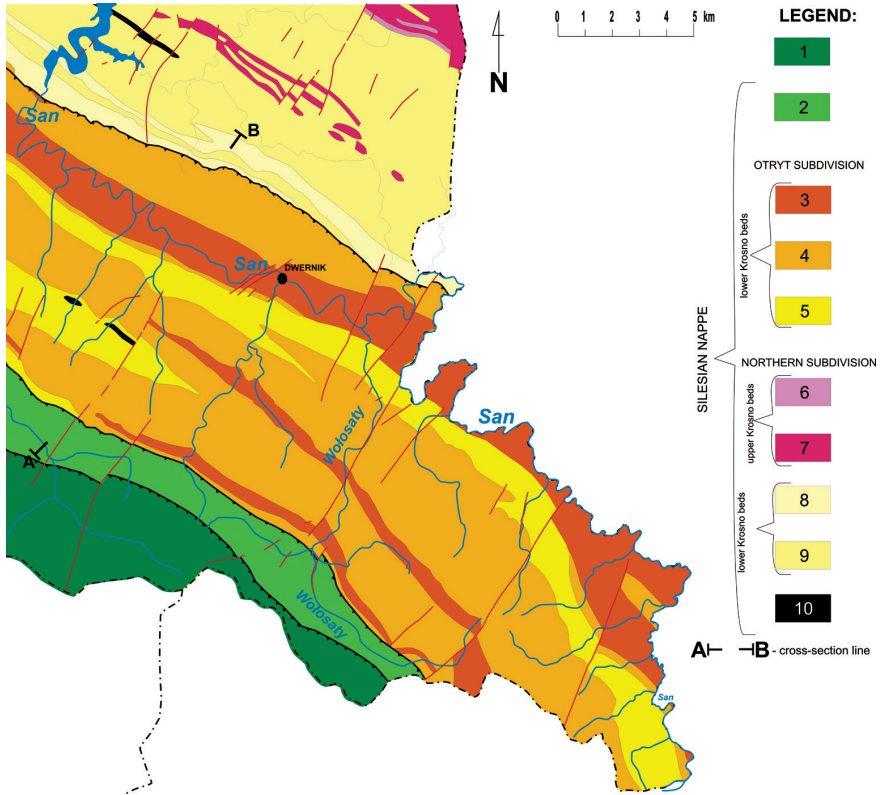


Fig. 8. Fragment of geological map of SE Poland, after [15]. Explanations: 1 – Dukla nappe, 2 – Fore-Dukla zone, 3 – thin- and medium-bedded sandstones with shales, 4 – coarse-bedded sandstones, 5 – thin- and medium-bedded sandstones with shales, with intercallations of coarse-bedded sandstones, 6 – shales and sandstones, 7 – sandstones and shales, 8 – thin- and medium-bedded sandstones and shales, 9 – coarse-bedded sandstones and shales, 10 – transition beds

Zatwarnica-Dwernik anticline is a part of Krosno beds. It is folded element, in which two uplifted zones separated by syncline are marked. Numerous transverse faults may extend into the depths and affect submerged tectonics. The occurrence of fractures and fault zones may be beneficial for the local improvement of the reservoir properties of Krosno compacted sandstones. The geological cross-section of part of Zatwarnica-Dwernik anticline and other tectonic units at area of SE Carpathians is presented at Figure 9.

Oil-bearing part of the Dwernik fold has been diagnosed using eight production wells. In the whole profile of the Krosno beds in sampled cores numerous signs of

hydrocarbons were observed. Studies have shown that the accumulation of hydrocarbons is associated mainly with the central level coarse-bedded and calcareous Krosno beds whose total thickness is approx. 500m. Their porosity ranges from 1–10%, and permeability from 0 to 0.7 mD. Such low values of reservoir parameters may indicate the presence of the system of micro fractures, from which oil production comes.

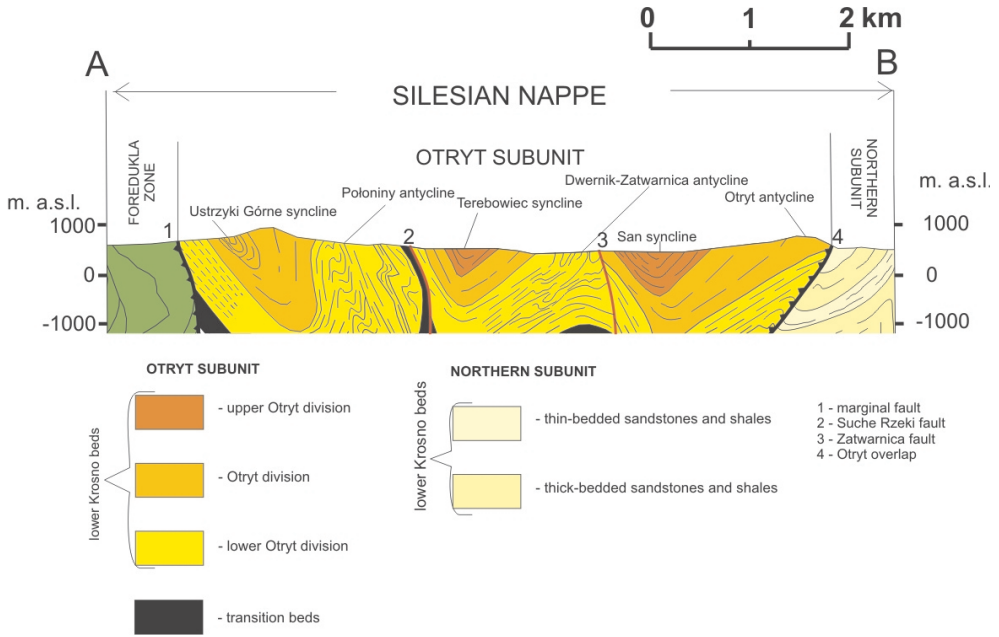


Fig. 9. Geological cross-section of Silesian nappe, after [15]

2.1. Comparison of geological layers of “shale oil” type in the US to Krosno beds

American formations of “shale oil” type, listed and described in Chapter 1 are characterized, like Krosno beds, by relatively low petrophysical properties. Comparison of selected properties of the US formations and Krosno beds are presented in Table 1.

However, geological structure of each formation is different. Bakken and Eagle Ford formations have a fairly simple geological structure, small thickness and they lie horizontally or at a slight angle. Avalon & Bone Springs formation is connected with a Permian pool, where carbonate platforms are present. Moreover, they are old formations (270–260 million years (Bakken and Avalon & Bone Springs) to 90 million years (Eagle Ford)). In addition, they differ considerably from Krosno beds as far as sedimentary and structural conditions are concerned, which are more approximated to areas of the Polish Lowland than Carpathians.

Table 1

A comparison of average selected properties of American oil formations and Krosno beds [2, 3, 9–11]

Parameters	Krosno beds	Bakken	Eagle Ford	Monterey	Avalon & Bone Springs
Thickness [m]	500–3500	25–30	70	700	200–500
Permeability [mD]	<0.03	0.03	<1	<1	<2
Porosity [%]	3	5	9	~11	~11
TOC [%]	5	8	4.25	7	5
The mineral composition [%]:					
Quartz	22–53	30–50	~ 13	~20	~55
Feldspars	6–31	5–7	n/a	to 35	~3
Carbonates	8–40	10–45	to 70	to 40	~15

Californian Monterey formation has quite a different (and much more complicated) construction from three previous formations. It shows strong resemblance to Krosno beds. It is younger than Krosno beds (6–16 million years in the case of Monterey formation, 25 million years in the case of Krosno beds). Lithologically Monterey formation is characterized, like Krosno beds, by the presence of shale and sandstone (in the case of Krosno beds coarse-bedded sandstones are present). It is mostly petroliferous formation. The similarity of the Monterey formation to Krosno beds can also be observed in tectonic construction because both areas are characterized by strong corrugation and folding of reservoirs. The burial depth of Monterey formation reaches 5000 m, and of Krosno beds 3000 meters. Production from the Monterey Formation currently comes from reservoirs associated with structural and stratigraphic traps, as is the case of the Carpathian deposits. In the formation of Monterey attempts of fracturing and acid treatment of petroliferous levels has been recorded [12, 13].

3. SUMMARY

The analysis of the geological setting of four American unconventional oil formations (Eagle Ford, Avalon & Bone Springs, Bakken and Monterey), was presented. These conditions were compared with Krosno beds. This formation is taken into account as perspective for unconventional oil exploitation.

After analyzing the geological structure of the oil-bearing formation in the USA and potential oil-bearing formations in Poland, it was concluded that geological conditions in

American Monterey formation, because of a similar age and complicated geological structure, as well as the average mineral composition (Tab. 1) have significant similarities to Polish Krosno beds. This may be a premise for adaptation of technologies used to produce from unconventional layers of Monterey formations to Polish conditions.

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